Ship Behaviour in Shallow and Confined Water: an Overview of Hydrodynamic Effects through EFD

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13-10-2011
Portsmouth
Introduction

Ship Behaviour in Shallow and Confined Water

- **Shallow and confined water areas in Flanders**
  - Canal Ghent-Terneuzen: interaction of maritime and inland fleet
  - Upper Sea-Scheldt: inland waterway

- **Effect on ship behaviour**
  - ship manoeuvring in open and shallow water
  - bank effects
  - ship-to-ship interaction
  - nautical bottom
Canal Ghent-Terneuzen

Designed for a panamax sized vessel increased to a beam of 37 m. 38 m is under investigation.
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  - Upper Sea-Scheldt: inland waterway
  - Port of Zeebrugge: nautical bottom – mud layer above a solid bottom
Introduction

Ship Behaviour in Shallow and Confined Water

Towing tank for manoeuvres in shallow water (co-operation Flanders Hydraulics Research – Ghent University)
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  - nautical bottom
  used for
  - admittance policy
  - inland navigation
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Ship Behaviour in Shallow and Confined Water

- **Effect on ship behaviour – video 38**
  18/04/2005 – Vlissingen – Springergeul
  Lykes Motivator 243 m x 32 m (103 dm)
  MSC Katherine Ann 184 m x 25 m (77 dm)
  Zarechensk 180 m x 28 m (107 dm)
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Ship manoeuvring in shallow water

- Literature review: manoeuvring performance
  - Ankudinov: “concept of modularity based on a separate representation of elements of the manoeuvring model”
  - Japan Towing Tank Committee: MMG model
Ship manoeuvring in shallow water

• Literature review: manoeuvring performance
  • Ankudinov
  • Japan Towing Tank Committee
  • Oltmann & Sharma, HSVA: four quadrant concept

8 knots
n = -80% n₀
10% UKC
Ship manoeuvring in shallow water

• Literature review: manoeuvring performance
  • Ankudinov
  • Japan Towing Tank Committee
  • Oltmann & Sharma, HSVA
  • Hydronautics Research: low speed manoeuvring models
  • Force Technology (DMI): look-up tables
  • Flanders Hydraulics Research: modular and tabular manoeuvring models (3 or 4 DOF) based on captive model tests and validated using free-running model tests and full scale measurements
Ship manoeuvring in shallow water

• Model tests
  
  • Flanders Hydraulics Research: increasing influence of chosen test parameters during captive model tests on the derived mathematical model when UKC is decreasing

<table>
<thead>
<tr>
<th>Test frequency</th>
<th>Test type</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% UKC</td>
<td>Oblique towing test, $N' = 0.010$</td>
</tr>
<tr>
<td>50% UKC</td>
<td>PMM highest frequency, $N' = 0.005$</td>
</tr>
<tr>
<td>150% UKC</td>
<td></td>
</tr>
</tbody>
</table>
Ship manoeuvring in shallow water

• Simulation model
  • **Flanders Hydraulics Research**: increasing influence of chosen test parameters during captive model tests on the derived mathematical model when UKC is decreasing
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  • ship manoeuvring in open and shallow water
  
  • **bank effects**

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  • nautical bottom

  used for

  • admittance policy

  • inland navigation
Ship behaviour due to bank effects

• Video
Ship behaviour due to bank effects

- Norrbin: “if the channel banks are not vertical walls but sloping beaches the definition of the bank distance parameter is less obvious.”, work extended by Ch’ng, Doctors and Renilson
  Which vertical reference height to measure the distance between a ship and a bank?
  Other formulations for the hydrodynamic changes in the water flow due to the vicinity of banks
- FHR and UGent: $d_{2b}$ and $m_{eq}$
  Weight distribution $e^{-a|y| - b|z|}$

\[
\begin{align*}
m_{eq} &= \frac{\text{[Diagram: Weight distribution]}}{d_{2b}}
\end{align*}
\]
Ship behaviour due to bank effects

Container carrier at 10 knots and 100% UKC, no propeller
Ship behaviour due to bank effects

container carrier
14kn
Bank IV'

\[
\frac{1}{d^2b} = \frac{Y/Y_{ref}}{[\cdot]}
\]
Ship behaviour due to bank effects

- KVLCC2 (10 knots, 50% UKC)
Ship behaviour due to bank effects

- KVLCC2
Ship behaviour due to bank effects

Real-time simulation study: meeting of two ULCS

Length 350 to 400 m
Beam 42.8 to 56.4 m
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Ship behaviour during ship-to-ship interaction

Knowledge Centre Manoeuvring in Shallow and Confined Water, Conference May 2011 hosted by NTNU and MARINTEK

• moored ships alongside quays;
• ships anchored or moored to buoys;
• ships meeting / passing on parallel / oblique / curved / steered paths;
• interaction with more than one ship or marine structure;
• ship-to-ship interaction during lightering operations;
• ship-to-ship interaction during tug assistance.
# Ship behaviour during ship-to-ship interaction

## Meeting and overtaking

- **Lightering Tug – ship interaction**

### Table

<table>
<thead>
<tr>
<th>Ship</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{pp}$</td>
<td>m</td>
<td>3.984</td>
<td>3.864</td>
<td>3.824</td>
</tr>
<tr>
<td>B</td>
<td>m</td>
<td>0.504</td>
<td>0.550</td>
<td>0.624</td>
</tr>
<tr>
<td>$T_{ref}$</td>
<td>m</td>
<td>0.180</td>
<td>0.180</td>
<td>0.207</td>
</tr>
<tr>
<td>$C_B$ (at $T_{ref}$)</td>
<td>-</td>
<td>0.843</td>
<td>0.588</td>
<td>0.816</td>
</tr>
<tr>
<td>T</td>
<td>m</td>
<td>0.155 – 0.200</td>
<td>0.155 – 0.200</td>
<td>0.136 – 0.256</td>
</tr>
</tbody>
</table>
Ship behaviour during ship-to-ship interaction

Project: KMB Investigating hydrodynamic aspect and control systems for ship-to-ship operations, co-ordinated by MARINTEK and financially supported by the Research Council of Norway

- **Zero longitudinal speed difference**
- **Special case of overtaking and overtaken**
- **Steady state and dynamic tests**
- **Open STS data**

<table>
<thead>
<tr>
<th>h</th>
<th>T_{STBL}</th>
<th>n_{STBL}</th>
<th>V</th>
<th>T_{SS}</th>
<th>ψ_{SS}</th>
<th>n_{SS}</th>
<th>δy</th>
<th>δx</th>
</tr>
</thead>
<tbody>
<tr>
<td>[m]</td>
<td>[m]</td>
<td>[-]</td>
<td>[kts]</td>
<td>[m]</td>
<td>[deg]</td>
<td>[-]</td>
<td>[m]</td>
<td>[m]</td>
</tr>
<tr>
<td>h_{max}</td>
<td>20.8</td>
<td>selfprop</td>
<td>2.0</td>
<td>7.5</td>
<td>180</td>
<td>Slow</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>1.35 T_{STBL}</td>
<td>12.8</td>
<td></td>
<td>4.0</td>
<td>15</td>
<td>179</td>
<td>Half</td>
<td>10</td>
<td>L/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.0</td>
<td>178</td>
<td>selfprop</td>
<td>25</td>
<td>-L/2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.0</td>
<td>177</td>
<td></td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>175</td>
<td></td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
Ship behaviour during ship-to-ship interaction

Lightering
Ship behaviour during ship-to-ship interaction

<table>
<thead>
<tr>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward speed [knots], full scale</td>
<td>5, 6, 7, 8, 9</td>
</tr>
<tr>
<td>Longitudinal separation (x'_{\text{rel}}) [-], from amidships of</td>
<td></td>
</tr>
<tr>
<td>container vessel to centre of gravity of tug (non-dimensional value based</td>
<td>0.73, 1.25, 1.77, 2.29, 2.82,</td>
</tr>
<tr>
<td>on length of tug)</td>
<td>3.33, 3.88, 4.41, 4.93</td>
</tr>
<tr>
<td>Transverse separation (y'_{\text{rel}}) [-], from centreline to</td>
<td></td>
</tr>
<tr>
<td>centreline (non-dimensional value based on breadth of tug)</td>
<td>2.6, 3.3, 4.0, 4.4, 5.3</td>
</tr>
<tr>
<td>Drift angle (\circ), negative angle bow-in since tug model is situated</td>
<td>-10, -5, 0, 5, 10</td>
</tr>
<tr>
<td>on starboard in the towing tank</td>
<td></td>
</tr>
</tbody>
</table>
Ship behaviour during ship-to-ship interaction

• Dedicated interaction models – complex pressure field change
• Different methodic combinations as EFD, CFD or other numerical codes
• JIP – ROPES, lead partner MARIN, Research on Passing Effects on Ships
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  used for
  - admittance policy
  - inland navigation
Nautical bottom

• PIANC: “nautical bottom as the level where physical characteristics of the bottom reach a critical limit beyond which contact with a ship’s keel causes either damage or unacceptable effects on controllability and manoeuvrability”

  • Multidisciplinary approach: measuring/survey techniques, dredging techniques, physical mud characteristics, effect of mud layers on the behaviour of ships
  • EFD and nautical bottom research = how incorporate viscous effects if Reynold’s law is not fulfilled? Mud layer is a homogeneous layer with constant density and rheological properties.
Nautical bottom

- Model tests at FHR
  - Layer thickness
  - Mud density
  - Mud viscosity
  - Under keel clearance

78 parameter combinations
Nautical bottom

- Results for the port of Zeebrugge
  - Density criterion is 1.2 ton/m³ instead of 1.15 ton/m³
  - Navigation through the mud (negative UKC’s water-mud interface)
  - 300 m length container ship -7% UKC assisted by two 45 ton tugs
- Main causes for the effect of mud layers on ship manoeuvrability:
  - Internal wave pattern in the water-mud interface greatly depended on mud density
  - Rheological characteristics of the mud: (non –) Newtonian fluid
- Development of in situ survey techniques
  STT sediment test tank
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Example 1: admittance policy

Admittance policy based on a certain window

- **Tidal water level (min. gross UKC, % ship’s draft):**
  - 15% coastal channels 1, 3
  - 12.5% for 2 and 4 (Dutch part)
  - 10% for 4 (Belgian part) and Z outer harbour
  - 1 m for Sea Canal Terneuzen – Ghent

- **Current (Z: 2 kn – 1.5 kn)**

- **Penetration in fluid mud (Z: 7%)**
Example 1: admittance policy

Admittance policy based on a gross UKC

Improved by a decision supporting tool ProToel:

- **Deterministic**: gross UKC (nautical bottom and top of fluid mud layers, lateral current component)
- **Probabilistic**: probability of bottom touch (due to squat and response to waves) < selected maximum value

Used for long term and short term decisions for the maximum allowable draft

Evaluation phase by the Flemish Pilotage and Shipping Assistance Devison for the port of Zeebrugge
Example 1: admittance policy

Admittance policy based on a window

Cross current

Min gross UKC nautical bottom

Penetration in fluid mud
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used for

• **admittance policy**
• **inland navigation**
Example 2: inland navigation

Design criteria for inland transport
Example 2: inland navigation

Simulation model based on captive model tests
- Ship manoeuvring in shallow water
- Bank effects
- STS interaction module
  based on generalised model
  for maritime ships
Example 2: inland navigation

Validation

• Multimodal captive model tests
• Free-running model tests
• Full scale measurements during trial voyages
• Real-time simulation by a skipper on the inland simulator Lara

Lateral force due to bank effects at fore and aft gauges
Summary

• Ship manoeuvrability decreases for UKC < 50% draft
• Complex hydrodynamic effects due to horizontal (bank, ship) and vertical (shallow water, nautical bottom) restrictions
• Knowledge based on different methodologies
  • Experimental fluid dynamics (force – water flow)
  • Computational fluid dynamics (pressure – water flow)
  • Numerical methods
• Co-operation